N88-22393

SPECIALTY THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS CODES

Joseph J. Lackney*
Sverdrup Technology, Inc.
(Lewis Research Center Group)
NASA Lewis Research Center

ABSTRACT

General-purpose finite element computer codes that can model inelastic material behavior have been available for more than a decade. However, these codes have not been accurate enough for use in analyzing hot-section engine components. To correct this problem, General Electric developed a series of nine new stand-alone computer codes for NASA. Because of the large temperature excursions associated with hot-section engine components, these codes have been designed to accommodate broad variations in material behavior, including plasticity and creep. The capabilities of these computer codes are summarized here.

*Work performed on-site at the Lewis Research Center for the Structural Mechanics Branch.

OBJECTIVE

Under a two-year program at the General Electric Company, a series of three-dimensional inelastic structural analysis computer codes were developed and delivered to NASA. The objective of this program was to develop analytical methods capable of evaluating the cyclic time-dependent inelasticity that occurs in hot-section engine components. Because of the large temperature excursions associated with hot-section engine components, the techniques developed had to be able to accommodate broad variations in material behavior, including plasticity and creep (McKnight et al., 1986). To meet this objective, a matrix consisting of three constitutive models and three element formulations was developed. A separate program for each combination of constitutive model and element formulation was written, making a total of nine programs. The source codes of the nine programs range in size from 7300 lines for the Bodner 20-node code to 19 000 lines for the Haisler-Allen nine-node code. The table below shows the length of each source code. All of the codes were given a stand-alone capability of performing cyclic nonlinear analysis.

Constitutive models	Element formulation		
	20-Node	8-Node	9-Node
Simple	8300	13,800	17,900
Classical	9200	16,300	19,000
Unified	7300	13,800	17,600

CD-88-31650

CONSTITUTIVE MODELS

The three constitutive models are a simple model, a classical model, and a unified model. In an inelastic analysis the simple model uses a bilinear stress-strain curve to determine the plastic strain and a power law equation to obtain the creep strain. The second model is the classical model of Allen and Haisler (1981). The third model is the unified model of Bodner, et al. (1979). The attributes of the three constitutive models are shown below. All of the models were programmed for a linear variation of loads and temperatures, with the material properties being temperature dependent.

Simple	Classical	Unified
• Uncoupled plasticity and creep	• Uncoupled plasticity and creep	• Coupled plasticity and creep
• Plasticity	• Plasticity	
Isotropic hardening	Combined isotropic and kinematic hardening	Isotropic hardening
Piecewise linear stress-strain curves	Piecewise linear stress-strain curves	No yield surface
Prandtl-Reuss flow rule	Modified Prandtl-Reuss flow rule	
• Creep	• Creep	
Steady state	Steady state	
Isotropic hardening	Isotropic hardening	
Prandtl-Reuss flow rule	Prandtl-Reuss flow rule	
Nonisothermal	Nonisothermal	

CD-88-31663

ELEMENT FORMULATIONS

The three element formulations available are an 8-node isoparametric shell element, a 9-node shell element, and a 20-node solid element. Both of the shell elements are obtained by degenerating three-dimensional isoparametric solid elements and then imposing the necessary kinematic assumptions in connection with a thin shell. The eight-node element uses serendipity shape functions for interpolation and Gaussian quadrature for numerical integration. The nine-node element uses Lagrange shape functions and Simpson's rule for numerical integration. The 20-node solid element uses Gaussian quadrature for integration. The attributes of these elements are listed below.

8-Node shell	9-Node shell	20-Node solid
• Five DOF 3 displacements 2 rotations	• Five DOF 3 displacements 2 rotations	• Three DOF (3 displacements)
• Serendipity shape functions	• Lagrange shape functions	
• No rotational stiffness about normal to mid-surface. Deleted before assembly	• Rotation about normal to midsurface treated as a prescribed displacement	
• Isotropic or orthotropic elastic properties	• Isotropic or orthotropic elastic properties	• Isotropic or orthotropic elastic properties
• Surface, line, nodal, rotational, thermal, and gravity loads	• Surface, line, nodal, rotational, thermal, and gravity loads	• Surface, nodal, rotational, thermal, and acceleration loads
• Prescribed displacements	• Prescribed displacements	• Prescribed displacements
• Gaussian quadrature used for numerical integration	• Simpson's rule used for numerical integration	• Gaussian quadrature used for numerical integration

CD-88-31664

INPUT FEATURES AND ANALYSIS TECHNIQUES

To analyze structures with linear material behavior, the nine codes use a blocked-column-skyline, out-of-core equation solver. To analyze structures with nonlinear material behavior, the codes use an initial stress iterative scheme. To increase the convergence rate of the iterative scheme, Aitken's acceleration scheme was incorporated into the codes.

The ability to model piecewise linear load histories was written into the codes. Since the inelastic strain rate can change dramatically during a linear load history, a dynamic time-incrementing procedure was included. The maximum inelastic strain increment, the maximum stress increment, and the maximum rate of change of the inelastic strain rate are the criteria that control the size of the time step. The minimum time step calculated from the three criteria is the value that is used.

In dynamic analysis the eigenvectors and eigenvalues can be extracted by using either the determinant search technique or the subspace iteration method. These methods are only included with those finite element codes containing the eight-node shell element. The table below lists the features of the nine codes.

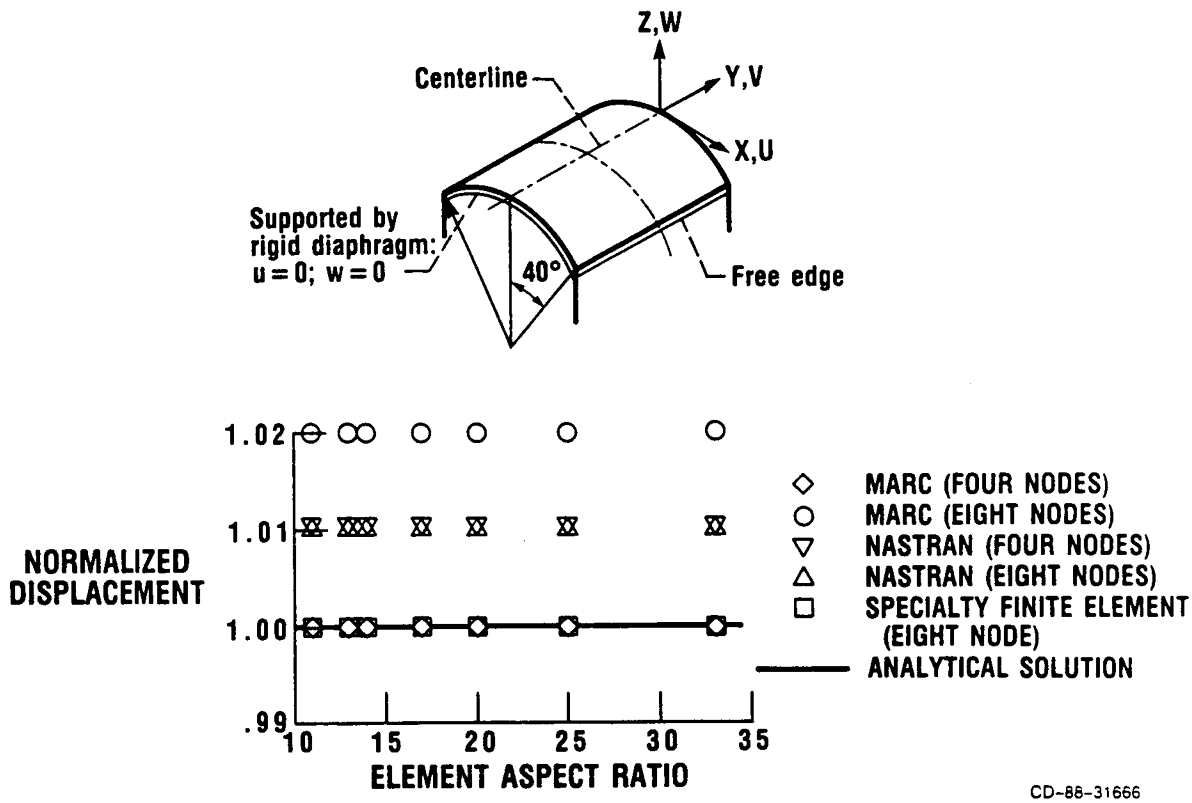
Feature[a]	Model								
	Simple			Classical			Unified		
	Number of nodes								
	8	9	20	8	9	20	8	9	20
Free format data input	x	x	x	x	x	x	x	x	x
Global coordinate system									
Cartesian	x	x	x	x	x	x	x	x	x
Spherical	x	x	na	x	x	na	x	x	na
Cylindrical	x	x	na	x	x	na	x	x	na
Local coordinate system									
Cartesian	x	x	x	x	x	x	x	x	x
Spherical	x	x	na	x	x	na	x	x	na
Cylindrical	x	x	na	x	x	na	x	x	na
Automatic generation of nodal coordinates	x	x	na	x	x	na	x	x	na
Automatic generation of element connectivities	x	x	na	x	x	na	x	x	na
Restart capability	x	x	x	x	x	x	x	x	x
Dynamic allocation	x	x	x	x	x	x	x	x	x
Blocked-column-skyline equation solver	x	x	x	x	x	x	x	x	x
Initial stress iterative scheme	x	x	x	x	x	x	x	x	x
Aitken's acceleration scheme	x	x	x	x	x	x	x	x	x
Dynamic time incrementing	x	x	x	x	x	x	x	x	x
Dynamic analysis	x	na	na	x	na	na	x	na	na
Material change option	x	x	x	x	x	x	x	x	x
Element removal option	x	x	na	x	x	na	x	x	na
Midside node generation	x	x	na	x	x	na	x	x	na
Skewed coordinate system	x	x	x	x	x	x	x	x	x
Orthotropic orientation definition	x	x	x	x	x	x	x	x	x

[a]x denotes "feature of the code"; na denotes "feature not yet available."

CD-88-31665

CYLINDRICAL SHELL ROOF

The cylindrical shell roof shown below has frequently been used to test the behavior of shell elements. The eight-node element is compared with the four-node and eight-node elements of both MARC and NASTRAN. As can be seen from the graph the specialty eight-node finite element compares very favorably with the other elements.



REFERENCES

Allen, D.H., and Haisler, W.E., 1981, "A Theory of Thermoplastic Materials, Computers and Structures," vol. 13, pp. 129-135.

Bodner, S.A., Partom, I., and Partom, Y., 1979, "Uniaxial Cyclic Loading of Elastic-Viscoplastic Material," ASME J. Appl. Mech., vol. 46, p. 805.

McKnight, R.L., Chen, P.C., Dame, L.T., Holt, R.V., Huang, Ho, Hortle, M., Gellin, S., Allen, D.H., and Haisler, W.E., 1986, "3-D Inelastic Analysis Methods for Hot Section Components," Turbine Engine Hot Section Technology, NASA CP-2444, pp. 257-268.